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Abstract: We report an investigation of the invariant mass spectrum of the two jets with highest transverse momentum in pp→W+2-jet and W+3-jet events to look for resonant enhancement. The data sample corresponds to an integrated luminosity of 5.0 fb-1 collected with the CMS detector at √s=7 TeV. We find no evidence for the anomalous structure reported by the CDF Collaboration, and establish an upper limit of 5.0 pb at 95% confidence level on the production cross section for a generic Gaussian signal with mass near 150 GeV. Additionally, we exclude two theoretical models that predict a CDF-like dijet resonance near 150 GeV.

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Study of the Dijet Mass Spectrum in $pp \to W +$ jets Events at $\sqrt{s} = 7$ TeV

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We report an investigation of the invariant mass spectrum of the two jets with highest transverse momentum in $pp \to W +$ 2-jet and $W +$ 3-jet events to look for resonant enhancement. The data sample corresponds to an integrated luminosity of 5.0 fb^{-1} collected with the CMS detector at $\sqrt{s} = 7$ TeV. We find no evidence for the anomalous structure reported by the CDF Collaboration, and establish an upper limit of 5.0 pb at 95% confidence level on the production cross section for a generic Gaussian signal with mass near 150 GeV. Additionally, we exclude two theoretical models that predict a CDF-like dijet resonance near 150 GeV.

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The CDF Collaboration reported evidence for an excess in the mass range 120–160 GeV in the invariant mass (m_{jj}) spectrum of the two leading transverse-momentum (p_T) jets produced in $p\bar{p} \to W +$ 2-jet events with a cross section of 4 pb [1]. The D0 Collaboration carried out a similar analysis but did not confirm the CDF result, instead setting a 95% confidence level (C.L.) upper limit of 1.9 pb on the cross section [2]. This Letter details the search for a bump-like enhancement in the m_{jj} spectrum in events with a W boson using 5.0 fb^{-1} of data collected from pp collisions at $\sqrt{s} = 7$ TeV with the Compact Muon Solenoid (CMS) detector at the CERN Large Hadron Collider (LHC) during 2010 and 2011.

We search for a resonance with a width consistent with detector resolution as reported by CDF. We further investigate three representative models, a technicolor π_T from the decay of a technicolor ρ_T [3], a leptophobic Z' decaying to two jets [4], and the standard model (SM) Higgs boson ($m_H = 150$ GeV) produced in association with a W boson (referred to as WH production) and decaying to a pair of jets. For the unknown state with detector resolution, we follow the convention used at the Tevatron of using the conservative WH simulation for analysis-dependent quantities like efficiencies and acceptances. The WH production cross section at the LHC is negligible compared to contributions from other SM processes, which overwhelm any contribution to this analysis from $WH \to \ell\nu jj$ decays for $m_H \approx 125$ GeV [5,6].

A detailed description of the CMS experiment can be found in Ref. [7]. The central feature of the CMS detector is a superconducting solenoid, of 6 m internal diameter, that produces an axial magnetic field of 3.8 T. Located within the field volume is the silicon pixel and strip tracker extending up to $|\eta| = 2.5$, as well as a lead tungstate crystal electromagnetic calorimeter (ECAL) and a brass and scintillator hadronic calorimeter (HCAL), both extending up to $|\eta| = 3$. Outside the field volume in the forward region ($3 < |\eta| < 5$) is an iron and quartz-fiber hadronic calorimeter. Muons are measured in gas-ionization detectors embedded in the steel return yoke outside the solenoid, in the pseudorapidity range $|\eta| < 2.4$. The CMS coordinate system has its origin at the center of the detector, with the z axis pointing along the direction of the counterclockwise proton beam. The azimuthal angle is denoted as ϕ, the polar angle as θ, and the pseudorapidity is defined as $\eta = -\ln[\tan(\theta/2)]$.

We employ selection criteria similar to those used at the Tevatron [1,2], but modified to adapt to the higher background rates and different experimental conditions at the LHC. We also place more stringent requirements on the jet kinematics, as suggested in Ref. [8], to enhance a signal compared to the irreducible W plus jets background.

Events are selected with one well-identified and isolated lepton (muon or electron), large missing transverse energy $\not\!\!E_T$, and exactly two or exactly three high-p_T jets. The data were collected with a suite of single-lepton triggers, mostly with a p_T threshold of 24 GeV for muons and 25–32 GeV for electrons. The trigger efficiency for the selected muons (electrons) is about 94% (90%). We reconstruct muon candidates in the region $|\eta| < 2.1$ by combining information from the silicon tracker and the muon detectors by means of a global fit. We identify electron candidates within $|\eta| < 1.44$ and $1.57 < |\eta| < 2.5$ as clustered energy deposits in the electromagnetic calorimeter that are matched to tracks. Muon and electron candidates need to fulfill quality criteria established for the measurement of the inclusive W and Z cross sections [9]. In addition, all leptons must be well-separated from hadronic activity in the event. Jets within an η-ϕ cone of radius 0.3 around a lepton candidate are removed.

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The muon (electron) transverse momentum must exceed 25 (35) GeV, and $\not{E}_T$ must be greater than 25 (30) GeV in the muon (electron) analysis. The transverse mass M_T of each W candidate must be greater than 50 GeV, where

$$M_T \equiv \sqrt{2p_T^{\ell}\not{E}_T[1-\cos(\phi_\ell - \phi_{\not{E}_T})]}$$

and ϕ_ℓ and $\phi_{\not{E}_T}$ are the azimuthal angles of the lepton and $\not{E}_T$, respectively. Events with more than one identified lepton are vetoed.

We reconstruct jets and $\not{E}_T$ [9,10] with the particle-flow algorithm [11], which combines information from several subdetectors. The jet finding uses the anti-k_T clustering algorithm [12] with a distance parameter of 0.5. We require $|\eta_{\text{jet}}| < 2.4$ to ensure that they lie within the tracker acceptance, and a minimum jet p_T of 30 GeV. Jets must satisfy identification criteria that eliminate jet candidates originating from noisy channels in the hadron calorimeter [13]. Jet-energy corrections are applied to account for the nonlinear response of the calorimeters to the particle energies and other instrumental effects. These corrections are based on *in situ* measurements using dijet, γ + jet, and Z + jet data samples [14]. Overlapping minimum-bias events from other pp collisions (pileup) and the underlying event can contribute additional energy to the reconstructed jets. The median energy density due to pileup is evaluated in each event and the corresponding energy is subtracted from each jet [15]. In addition, tracks that do not originate from the primary vertex are not considered for jet clustering [16]. We verify that the procedures successfully remove the dependence of jet response on the number of interactions in a single event. The jet p_T resolution varies from 15% at $p_T = 40$ GeV to 6% at $p_T = 400$ GeV [14]. We evaluate the mass resolution σ_{jj} for a selected jet pair using simulation and verify it using hadronic W decays in data. We find σ_{jj} to be 10% of m_{jj} for masses around 150 GeV.

We require $\|\vec{p}_T{}^{j_1} + \vec{p}_T{}^{j_2}\| > 45$ GeV and $|\Delta\eta(j_1, j_2)| < 1.2$, where the jets are numbered in order of decreasing p_T. We retain events with exactly two or exactly three jets satisfying $p_T > 30$ GeV and with the leading jet having $p_T > 40$ GeV and pointing more than 0.4 rad in azimuth from the direction of the $\not{E}_T$. The selected jets and the lepton from the W decay must originate from the same primary vertex. Additionally, we impose $0.3 < p_T{}^{j_2}/m_{jj} < 0.7$ to take advantage of the Jacobian nature of resonant dijet production as observed in simulation studies compared with nonresonant W plus jets production.

W production with two or more jets dominates the selected sample. Smaller contributions come from top-pair and single-top decays, Drell-Yan events with two or more jets, multijet production, and WW and WZ diboson production where one W decays into leptons and the other W or Z decays into quarks.

The shapes of the m_{jj} distributions for background processes are modeled using samples of simulated events. The MADGRAPH5 1.3.30 [17] event generator produces parton-level events with a W boson and up to four partons on the basis of matrix-element (ME) calculations. (The Tevatron experiments used the ALPGEN generator [18].) The ME-parton shower matching scale μ is taken to be 20 GeV [19], and the factorization and renormalization scales are set to $q^2 = M_W^2 + p_{T,W}^2$. Samples of $t\bar{t}$ and Drell-Yan events are also generated with MADGRAPH. Single-top production is modeled with POWHEG 1.0 [20]. Multijet and diboson samples (WW, WZ, ZZ) are generated with PYTHIA 6.422 [21]. PYTHIA provides the parton shower simulation in all cases, with parameters of the underlying event set to the Z2 tune [22]. The set of parton distribution functions used is CTEQ6LL [23]. A GEANT4-based simulation [24] of the CMS detector is used in the production of all Monte Carlo (MC) samples. Multiple proton-proton interactions within a bunch crossing are simulated, and the triggers are emulated. All simulated events are reconstructed and analyzed with the same software as data.

We generate signal samples for the WH model using PYTHIA, with parameters corresponding a SM Higgs boson with $m_H = 150$ GeV. We use PYTHIA for technicolor generation as well. We generate leptophobic Z' with MADGRAPH. The authors of Refs. [3,4] provided values for masses and other parameters of the technicolor and Z' models that would best correspond to the signal observed by CDF.

We determine the contributions of the known SM processes to the observed m_{jj} spectrum by means of an extended unbinned maximum-likelihood fit in the range between 40 GeV and 400 GeV. We fit separately in four event categories, $\{\mu, e\} \times \{$2-jet, 3-jet$\}$, because the background compositions differ. The m_{jj} signal region, 123 to 186 GeV, corresponding to $\pm 2\sigma_{jj}$, is excluded from this fit in order to arrive at an unbiased estimate of a possible resonant enhancement in this region.

Table I lists the SM processes included in the fit. The W plus jets normalization is a free fit parameter because it is by far the dominant background. We allow the

TABLE I. Treatment of background m_{jj} shapes and normalizations in a fit to the data. The background normalizations are constrained within the fit to Gaussian distributions with the listed central values and widths.

Process	Shape	Constraint on normalization
W plus jets	MC and data	Unconstrained
Diboson	MC	61.2 pb ± 10%(NLO) [25]
$t\bar{t}$	MC	163 pb ± 7%(NLO) [26]
Single-top	MC	84.9 pb ± 5%(NNLL) [27–29]
Drell-Yan plus jets	MC	3.05 nb ± 4.3%(NNLO) [30]
Multijet (QCD)	data	$\not{E}_T$ fit (described in text)

normalizations of the other background components to vary within Gaussian constraints around the central values also listed in Table I. The central values for all processes except multijet come from next-to-leading-order (NLO), next-to-next-to-leading-log (NNLL), or next-to-NLO (NNLO) calculations, and the constraints reflect the published uncertainties. We derive templates for the m_{jj} distribution for each background from simulation except for the multijet events, which contribute when jets are misidentified as leptons. In a separate fit to events that fail the lepton isolation requirements, we determine the central value of the multijet normalization, the constraint on the normalization and the template for the m_{jj} distribution [9]. The fit to data determines the correlations among the various fit parameters.

The default CMS MADGRAPH sample of the dominant W plus jets background does not describe well the m_{jj} spectrum in the m_{jj} sidebands. Four alternative samples of W events, with the scales μ and q increased and reduced by a factor two with respect to those of the default, fail to provide significant improvement. Thus, we employ an empirically driven combination of three shapes to describe this component in the fit model,

$$F_{W+\text{jets}} = \alpha \mathcal{F}_{W+\text{jets}}(\mu_0^2, q'^2) + \beta \mathcal{F}_{W+\text{jets}}(\mu'^2, q_0^2) + (1-\alpha-\beta)\mathcal{F}_{W+\text{jets}}(\mu_0^2, q_0^2),$$

where $\mathcal{F}_{W+\text{jets}}$ denotes the m_{jj} shape from simulation. The parameters μ_0 (μ') and q_0 (q') correspond to the default (alternative) values of μ and q, respectively, while fractional contributions α and β are free to vary between 0 and 1. We take $\mu' = 2\mu_0$ or $0.5\mu_0$ ($q' = 2q_0$ or $0.5q_0$), depending on which alternative sample provides a better fit to data. Furthermore, we verify, via pseudoexperiment simulations generated with an alternate shape, that the function in the above equation has sufficient freedom to describe the W plus jets shape.

Figure 1(a) shows the observed m_{jj} distribution for all four event categories combined, together with the fitted projections of the contributions of various SM processes. Figure 1(b) shows the same distribution after subtraction of all SM contributions from data except electroweak diboson WW/WZ events. No peak is visible in the spectrum except that near 80 GeV due to diboson events. Figure 1(c) shows the bin-by-bin pull. Table II presents the yields of the SM components obtained from the fit. The sum of all the contributions is compared to the number of observed events. All numbers except those in the last two rows are for the m_{jj} range of 40 to 400 GeV. The last two rows compare the observed number of events and the number predicted by the fit in the m_{jj} range of 123 to 186 GeV. The data agree with the SM expectations, and we find no significant excess in the signal region. We observe a sizable deficit in the muon 2-jet data with respect to the prediction from our model. We do not observe similar deviations in the other three categories, suggesting it is a fluctuation and not a systematic bias.

We validate the fit procedure by performing pseudoexperiments. In each experiment, we generate the m_{jj} pseudodata of the SM processes, including the correlations taken from the fit to data, and then fit each pseudodata sample. The results indicate that the bias on the total yield is below 0.2% and that the fit underestimates the total yield uncertainty by about 30%. These effects are corrected for in the final result. Uncertainties in the jet energy are estimated using a sample of W bosons decaying hadronically in a pure sample of semileptonic $t\bar{t}$ events. The mean and resolution of the reconstructed dijet mass distribution

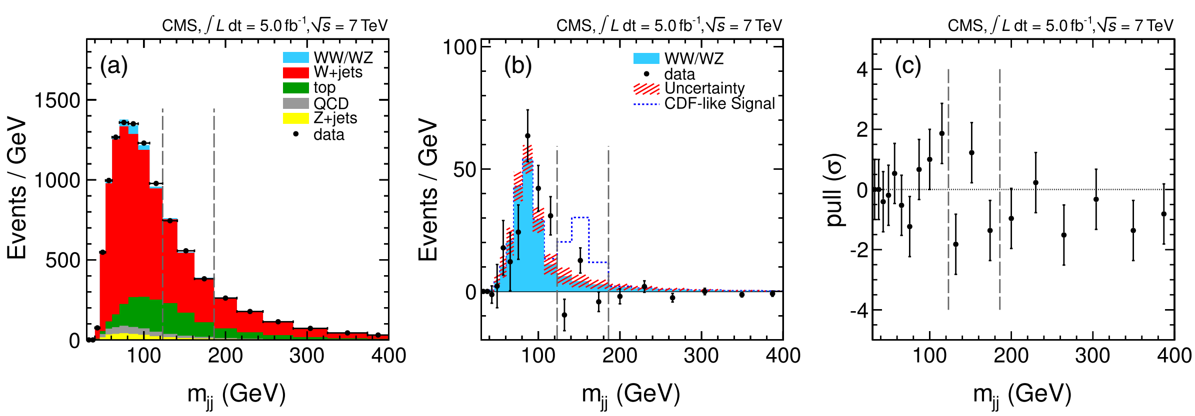

FIG. 1 (color online). (a) Distribution of the invariant mass spectrum of the leading two jets observed in data. Overlaid are the fit projections of the various components. The region between the vertical dashed lines is excluded from the fit. (b) The same distribution after subtraction of all SM components except the electroweak processes WW/WZ. Error bars correspond to the statistical uncertainties. The hatched band represents the uncertainty on the sum of the SM components including correlations from the fit. The dark blue histogram is a resonance consistent with detector resolution and normalized to the CDF cross section scaled as described in the text. (c) The bin-by-bin pull, (data fit)/(fit uncertainty). The bins in the figures are representative of the expected resolution for a given mass and the number of entries in each bin is scaled by its width.

TABLE II. Event yields determined from maximum-likelihood fits to the data. The total fit yields are corrected for bias. The total fit uncertainties include the correlations among the various yields, as determined by the fit, and the corrections derived from the fit validation described in the text. The χ^2 probability uses the residuals and the data and MC statistical errors.

	Muons		Electrons	
Process	2-jet	3-jet	2-jet	3-jet
W plus jets	$58\,919 \pm 530$	$13\,069 \pm 366$	$29\,787 \pm 1153$	8397 ± 292
Dibosons	1236 ± 114	333 ± 32	685 ± 65	184 ± 18
$t\bar{t}$	4570 ± 307	9049 ± 382	2556 ± 174	4265 ± 253
Single-top	1765 ± 87	1001 ± 50	916 ± 46	521 ± 26
Drell-Yan plus jets	1837 ± 79	561 ± 24	1061 ± 46	364 ± 16
Multijet (QCD)	29 ± 284	0 ± 90	3944 ± 1133	324 ± 160
Fit χ^2 probability	0.454	0.729	0.969	0.991
Total from fit	$68\,294 \pm 307$	$24\,013 \pm 193$	$38\,949 \pm 228$	$14\,055 \pm 143$
Data	67 900	24 046	38 973	14 145
In the signal region $123 < m_{jj} < 186$ GeV (excluded from the fit)				
Total predicted	$14\,511 \pm 125$	7739 ± 95	7944 ± 92	4347 ± 70
Data	14 050	7751	8023	4438

in data agree within 0.6% with the expectation from simulation. A small difference in $\not{E}_T$ resolution [10] between data and simulation affects the signal acceptance for the new physics models under consideration at the 0.5% level. Further systematic uncertainties are due to the uncertainty of the trigger efficiency estimates (1%) and the estimate of lepton reconstruction and selection efficiency (2%) [9]. The uncertainty on the integrated luminosity is 2.2% [31].

We scrutinize the dijet mass spectrum near 150 GeV, searching for a technicolor, leptophobic Z', or WH resonant enhancement. We also use a generic signal model obtained by convolving a delta function centered at $m_{jj} = 150$ GeV with a Gaussian function having width equal to σ_{jj}. Figure 1(b) shows this generic signal shape. The expected number of signal events at the LHC for a given cross section at the Tevatron can be estimated by considering the ratio of the predicted cross sections for our reference process, WH production with $M_H = 150$ GeV. This process is dominated by quark-antiquark ($q\bar{q}$) annihilation. As $q\bar{q}$ processes have the smallest increase in parton luminosity from the Tevatron to the LHC, this choice provides a conservative limit. We therefore assume

$$\sigma_{\mathrm{LHC}}^{\text{dijet resonance}} = \sigma_{\mathrm{Tevatron}}^{\text{dijet resonance}} \frac{\sigma_{\mathrm{LHC}}^{WH}}{\sigma_{\mathrm{Tevatron}}^{WH}},$$

where $\sigma_{\mathrm{LHC}}^{WH} = 300.1$ fb [32] and $\sigma_{\mathrm{Tevatron}}^{WH} = 71.8$ fb [33]. A generic Gaussian signal normalized to $\sigma_{\mathrm{Tevatron}} = 4$ pb corresponds to $\sigma_{\mathrm{LHC}} = 16.7$ pb. Table III contains the values of σ_{LHC} times the branching fraction to jets and of the overall efficiency times acceptance $\varepsilon\mathcal{A}$ for the models considered.

Since we observe no resonant enhancement, we proceed to set exclusion limits using a modified frequentist $\mathrm{CL_S}$ method [34,35] with profile likelihood as the test statistic. Inputs to the limit-setting procedure are the m_{jj} distribution obtained by combining the SM components from the fit, the observed distribution in data, the expectation from the dijet resonance model under consideration, and the uncertainties associated with these quantities. Figure 2(a) shows the observed and expected $\mathrm{CL_S}$ values versus cross section for a generic Gaussian signal, after combining the results of all four event categories. We set a 95% C.L. upper limit of 5.0 pb and a 99.9% C.L. upper limit of 8.5 pb on the dijet production cross section for a generic resonance with WH-like $\varepsilon\mathcal{A}$.

Figure 2(b) compares the 95% C.L. upper limits with the expected cross sections for technicolor, leptophobic Z', and WH ($M_H = 150$ GeV) signals. The technicolor and Z' models are excluded. Because we have minimal sensitivity to WH, we compare the limit in Fig. 2(b) to 100 times the SM cross section as an illustration.

In summary, we have studied the invariant mass spectrum of the two jets with highest transverse momentum in

TABLE III. The PYTHIA cross sections at 7 TeV times branching fraction to jets ($\sigma \times \mathcal{B}$) and overall efficiency times acceptance ($\varepsilon\mathcal{A}$) for various signal models. The relative uncertainties in ε measurements are 1–2%. The uncertainty on $\mathcal{A}$ is negligible.

		$\varepsilon\mathcal{A}$			
		Muons		Electrons	
Signal model	$\sigma \times \mathcal{B}$ (pb)	2-jet	3-jet	2-jet	3-jet
Technicolor [3]	7.4	0.065	0.020	0.039	0.011
Z' [4]	8.1	0.070	0.023	0.042	0.014
WH [21]	0.059	0.060	0.019	0.038	0.013

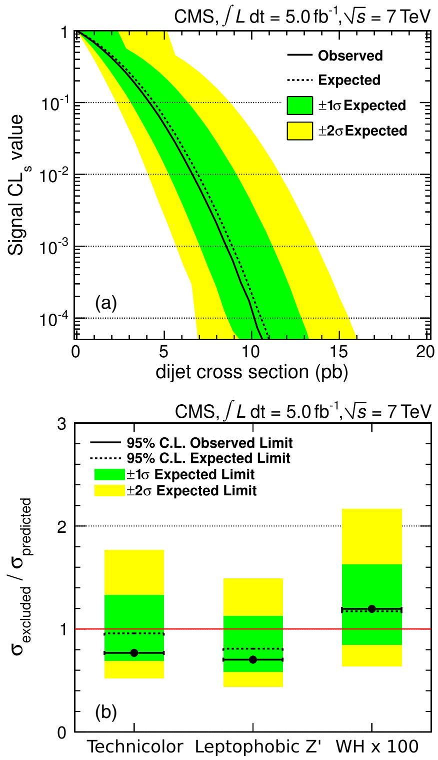

FIG. 2 (color online). (a) The observed and expected values of the CL_S statistic for a generic Gaussian signal hypothesis with $M = 150$ GeV and $\sigma_{jj} = 15$ GeV, as a function of the dijet signal cross section. (b) Observed and expected 95% C.L. upper limits, with one- and two-sigma error bands, on the cross section divided by the expected values for various signal models. The limits are calculated using the CL_S method. A value of the excluded cross section over the predicted cross section of less than one indicates that the model is excluded at 95% C.L. Table III lists the cross sections for these models.

$pp \to W + 2$-jet and $W + 3$-jet events, with the W decaying leptonically to a muon or electron. The analyzed data sample corresponds to an integrated luminosity of 5.0 fb^{-1} at $\sqrt{s} = 7$ TeV. We find no evidence for a resonant enhancement near a dijet mass of 150 GeV, as reported by the CDF Collaboration, and set upper limits on the dijet production cross section of 5.0 pb at 95% C.L. and 8.5 pb at 99.9% C.L. Two theoretical models, leptophobic Z' and technicolor, which predict the presence of a resonant enhancement near 150 GeV, are excluded.

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[1] T. Aaltonen *et al.* (CDF Collaboration), Phys. Rev. Lett. **106**, 171801 (2011).
[2] V. M. Abazov (D0 Collaboration), Phys. Rev. Lett. **107**, 011804 (2011).
[3] E. J. Eichten, K. Lane, and A. Martin, Phys. Rev. Lett. **106**, 251803 (2011).
[4] M. R. Buckley, D. Hooper, J. Kopp, and E. T. Neil, Phys. Rev. D **83**, 115013 (2011).
[5] S. Chatrchyan *et al.* (CMS Collaboration), Phys. Lett. B **716**, 30 (2012).
[6] G. Aad *et al.* (ATLAS Collaboration), Phys. Lett. B **716**, 1 (2012).
[7] S. Chatrchyan *et al.* (CMS Collaboration), JINST **3**, S08004 (2008).
[8] E. Eichten, K. Lane, and A. Martin, arXiv:1107.4075.
[9] S. Chatrchyan *et al.* (CMS Collaboration), J. High Energy Phys. 10 (2011) 132.
[10] S. Chatrchyan *et al.* (CMS Collaboration), JINST **6**, P09001 (2011).
[11] CMS Collaboration, Report No. CMS-PAS-PFT-09- 001, 2009.
[12] M. Cacciari, G. P. Salam, and G. Soyez, J. High Energy Phys. 04 (2008) 063.
[13] S. Chatrchyan *et al.* (CMS Collaboration), JINST **5**, T03014 (2010).
[14] S. Chatrchyan *et al.* (CMS Collaboration), JINST **6**, P11002 (2011).
[15] M. Cacciari and G. P. Salam, Phys. Lett. B **659**, 119 (2008).
[16] M. Cacciari, G. P. Salam, and G. Soyez, J. High Energy Phys. 04 (2008) 005.
[17] F. Maltoni and T. Stelzer, J. High Energy Phys. 02 (2003) 027.
[18] M. L. Mangano, M. Moretti, F. Piccinini, R. Pittau, and A. D. Polosa, J. High Energy Phys. 07 (2003) 001.
[19] S. Hoeche, F. Krauss, N. Lavesson, L. Lonnblad, M. Mangano, A. Schaelicke, and S. Schumann, arXiv:hep-ph/0602031.
[20] S. Frixione, P. Nason, and C. Oleari, J. High Energy Phys. 11 (2007) 070.
[21] T. Sjostrand, S. Mrenna, and P. Z. Skands, J. High Energy Phys. 05 (2006) 026.

[22] S. Chatrchyan *et al.* (CMS Collaboration), J. High Energy Phys. 09 (2011) 109.
[23] H.-L. Lai, J. Huston, Z. Li, P. Nadolsky, J. Pumplin, D. Stump, and C.-P. Yuan, Phys. Rev. D **82**, 054021 (2010).
[24] S. Agostinelli *et al.* (GEANT4 Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).
[25] J. M. Campbell, R. K. Ellis, and C. Williams, J. High Energy Phys. 7 (2011) 018.
[26] N. Kidonakis, Phys. Rev. D **82**, 114030 (2010).
[27] N. Kidonakis, Phys. Rev. D **81**, 054028 (2010).
[28] N. Kidonakis, Phys. Rev. D **83**, 091503 (2011).
[29] N. Kidonakis, Phys. Rev. D **82**, 054018 (2010).
[30] K. Melnikov and F. Petriello, Phys. Rev. D **74**, 114017 (2006).
[31] CMS Collaboration, Report No. CMS-PAS-SMP-12-008, 2012.
[32] S. Dittmaier, C. Mariotti, G. Passarino, and R. Tanaka (LHC Higgs Cross Section Working Group), arXiv:1101.0593.
[33] M. S. Carena *et al.* (Higgs Working Group), arXiv:hep-ph/0010338.
[34] A. L. Read, Report No. CERN-OPEN-2000- 005, 2000.
[35] T. Junk, Nucl. Instrum. Methods Phys. Res., Sect. A **434**, 435 (1999).

S. Chatrchyan,[1] V. Khachatryan,[1] A. M. Sirunyan,[1] A. Tumasyan,[1] W. Adam,[2] E. Aguilo,[2] T. Bergauer,[2] M. Dragicevic,[2] J. Erö,[2] C. Fabjan,[2,b] M. Friedl,[2] R. Frühwirth,[2,b] V. M. Ghete,[2] J. Hammer,[2] N. Hörmann,[2] J. Hrubec,[2] M. Jeitler,[2,b] W. Kiesenhofer,[2] V. Knünz,[2] M. Krammer,[2,b] I. Krätschmer,[2] D. Liko,[2] I. Mikulec,[2] M. Pernicka,[2,a] B. Rahbaran,[2] C. Rohringer,[2] H. Rohringer,[2] R. Schöfbeck,[2] J. Strauss,[2] A. Taurok,[2] W. Waltenberger,[2] G. Walzel,[2] E. Widl,[2] C.-E. Wulz,[2,b] V. Mossolov,[3] N. Shumeiko,[3] J. Suarez Gonzalez,[3] M. Bansal,[4] S. Bansal,[4] T. Cornelis,[4] E. A. De Wolf,[4] X. Janssen,[4] S. Luyckx,[4] L. Mucibello,[4] S. Ochesanu,[4] B. Roland,[4] R. Rougny,[4] M. Selvaggi,[4] Z. Staykova,[4] H. Van Haevermaet,[4] P. Van Mechelen,[4] N. Van Remortel,[4] A. Van Spilbeeck,[4] F. Blekman,[5] S. Blyweert,[5] J. D'Hondt,[5] R. Gonzalez Suarez,[5] A. Kalogeropoulos,[5] M. Maes,[5] A. Olbrechts,[5] W. Van Doninck,[5] P. Van Mulders,[5] G. P. Van Onsem,[5] I. Villella,[5] B. Clerbaux,[6] G. De Lentdecker,[6] V. Dero,[6] A. P. R. Gay,[6] T. Hreus,[6] A. Léonard,[6] P. E. Marage,[6] T. Reis,[6] L. Thomas,[6] G. Vander Marcken,[6] C. Vander Velde,[6] P. Vanlaer,[6] J. Wang,[6] V. Adler,[7] K. Beernaert,[7] A. Cimmino,[7] S. Costantini,[7] G. Garcia,[7] M. Grunewald,[7] B. Klein,[7] J. Lellouch,[7] A. Marinov,[7] J. Mccartin,[7] A. A. Ocampo Rios,[7] D. Ryckbosch,[7] N. Strobbe,[7] F. Thyssen,[7] M. Tytgat,[7] P. Verwilligen,[7] S. Walsh,[7] E. Yazgan,[7] N. Zaganidis,[7] S. Basegmez,[8] G. Bruno,[8] R. Castello,[8] L. Ceard,[8] C. Delaere,[8] T. du Pree,[8] D. Favart,[8] L. Forthomme,[8] A. Giammanco,[8,c] J. Hollar,[8] V. Lemaitre,[8] J. Liao,[8] O. Militaru,[8] C. Nuttens,[8] D. Pagano,[8] A. Pin,[8] K. Piotrzkowski,[8] N. Schul,[8] J. M. Vizan Garcia,[8] N. Beliy,[9] T. Caebergs,[9] E. Daubie,[9] G. H. Hammad,[9] G. A. Alves,[10] M. Correa Martins Junior,[10] D. De Jesus Damiao,[10] T. Martins,[10] M. E. Pol,[10] M. H. G. Souza,[10] W. L. Aldá Júnior,[11] W. Carvalho,[11] A. Custódio,[11] E. M. Da Costa,[11] C. De Oliveira Martins,[11] S. Fonseca De Souza,[11] D. Matos Figueiredo,[11] L. Mundim,[11] H. Nogima,[11] V. Oguri,[11] W. L. Prado Da Silva,[11] A. Santoro,[11] L. Soares Jorge,[11] A. Sznajder,[11] T. S. Anjos,[12,d] C. A. Bernardes,[12,d] F. A. Dias,[12,e] T. R. Fernandez Perez Tomei,[12] E. M. Gregores,[12,d] C. Lagana,[12] F. Marinho,[12] P. G. Mercadante,[12,d] S. F. Novaes,[12] Sandra S. Padula,[12] V. Genchev,[13,f] P. Iaydjiev,[13,f] S. Piperov,[13] M. Rodozov,[13] S. Stoykova,[13] G. Sultanov,[13] V. Tcholakov,[13] R. Trayanov,[13] M. Vutova,[13] A. Dimitrov,[14] R. Hadjiiska,[14] V. Kozhuharov,[14] L. Litov,[14] B. Pavlov,[14] P. Petkov,[14] J. G. Bian,[15] G. M. Chen,[15] H. S. Chen,[15] C. H. Jiang,[15] D. Liang,[15] S. Liang,[15] X. Meng,[15] J. Tao,[15] J. Wang,[15] X. Wang,[15] Z. Wang,[15] H. Xiao,[15] M. Xu,[15] J. Zang,[15] Z. Zhang,[15] C. Asawatangtrakuldee,[16] Y. Ban,[16] S. Guo,[16] Y. Guo,[16] W. Li,[16] S. Liu,[16] Y. Mao,[16] S. J. Qian,[16] H. Teng,[16] D. Wang,[16] L. Zhang,[16] B. Zhu,[16] W. Zou,[16] C. Avila,[17] J. P. Gomez,[17] B. Gomez Moreno,[17] A. F. Osorio Oliveros,[17] J. C. Sanabria,[17] N. Godinovic,[18] D. Lelas,[18] R. Plestina,[18,g] D. Polic,[18] I. Puljak,[18,f] Z. Antunovic,[19] M. Kovac,[19] V. Brigljevic,[20] S. Duric,[20] K. Kadija,[20] J. Luetic,[20] S. Morovic,[20] A. Attikis,[21] M. Galanti,[21] G. Mavromanolakis,[21] J. Mousa,[21] C. Nicolaou,[21] F. Ptochos,[21] P. A. Razis,[21] M. Finger,[22] M. Finger, Jr.,[22] Y. Assran,[23,h] S. Elgammal,[23,i] A. Ellithi Kamel,[23,j] S. Khalil,[23,i] M. A. Mahmoud,[23,k] A. Radi,[23,l,m] M. Kadastik,[24] M. Müntel,[24] M. Raidal,[24] L. Rebane,[24] A. Tiko,[24] P. Eerola,[25] G. Fedi,[25] M. Voutilainen,[25] J. Härkönen,[26] A. Heikkinen,[26] V. Karimäki,[26] R. Kinnunen,[26] M. J. Kortelainen,[26] T. Lampén,[26] K. Lassila-Perini,[26] S. Lehti,[26] T. Lindén,[26] P. Luukka,[26] T. Mäenpää,[26] T. Peltola,[26] E. Tuominen,[26] J. Tuominiemi,[26] E. Tuovinen,[26] D. Ungaro,[26] L. Wendland,[26] K. Banzuzi,[27] A. Karjalainen,[27] A. Korpela,[27] T. Tuuva,[27] M. Besancon,[28] S. Choudhury,[28] M. Dejardin,[28] D. Denegri,[28] B. Fabbro,[28] J. L. Faure,[28] F. Ferri,[28] S. Ganjour,[28] A. Givernaud,[28] P. Gras,[28] G. Hamel de Monchenault,[28] P. Jarry,[28] E. Locci,[28] J. Malcles,[28] L. Millischer,[28] A. Nayak,[28] J. Rander,[28] A. Rosowsky,[28] I. Shreyber,[28] M. Titov,[28] S. Baffioni,[29] F. Beaudette,[29] L. Benhabib,[29] L. Bianchini,[29] M. Bluj,[29,n] C. Broutin,[29] P. Busson,[29] C. Charlot,[29] N. Daci,[29] T. Dahms,[29] L. Dobrzynski,[29] R. Granier de Cassagnac,[29]

M. Haguenauer,[29] P. Miné,[29] C. Mironov,[29] I. N. Naranjo,[29] M. Nguyen,[29] C. Ochando,[29] P. Paganini,[29] D. Sabes,[29] R. Salerno,[29] Y. Sirois,[29] C. Veelken,[29] A. Zabi,[29] J.-L. Agram,[30,o] J. Andrea,[30] D. Bloch,[30] D. Bodin,[30] J.-M. Brom,[30] M. Cardaci,[30] E. C. Chabert,[30] C. Collard,[30] E. Conte,[30,o] F. Drouhin,[30,o] C. Ferro,[30] J.-C. Fontaine,[30,o] D. Gelé,[30] U. Goerlach,[30] P. Juillot,[30] A.-C. Le Bihan,[30] P. Van Hove,[30] F. Fassi,[31] D. Mercier,[31] S. Beauceron,[32] N. Beaupere,[32] O. Bondu,[32] G. Boudoul,[32] J. Chasserat,[32] R. Chierici,[32,f] D. Contardo,[32] P. Depasse,[32] H. El Mamouni,[32] J. Fay,[32] S. Gascon,[32] M. Gouzevitch,[32] B. Ille,[32] T. Kurca,[32] M. Lethuillier,[32] L. Mirabito,[32] S. Perries,[32] V. Sordini,[32] Y. Tschudi,[32] P. Verdier,[32] S. Viret,[32] Z. Tsamalaidze,[33,p] G. Anagnostou,[34] S. Beranek,[34] M. Edelhoff,[34] L. Feld,[34] N. Heracleous,[34] O. Hindrichs,[34] R. Jussen,[34] K. Klein,[34] J. Merz,[34] A. Ostapchuk,[34] A. Perieanu,[34] F. Raupach,[34] J. Sammet,[34] S. Schael,[34] D. Sprenger,[34] H. Weber,[34] B. Wittmer,[34] V. Zhukov,[34,q] M. Ata,[35] J. Caudron,[35] E. Dietz-Laursonn,[35] D. Duchardt,[35] M. Erdmann,[35] R. Fischer,[35] A. Güth,[35] T. Hebbeker,[35] C. Heidemann,[35] K. Hoepfner,[35] D. Klingebiel,[35] P. Kreuzer,[35] C. Magass,[35] M. Merschmeyer,[35] A. Meyer,[35] M. Olschewski,[35] P. Papacz,[35] H. Pieta,[35] H. Reithler,[35] S. A. Schmitz,[35] L. Sonnenschein,[35] J. Steggemann,[35] D. Teyssier,[35] M. Weber,[35] M. Bontenackels,[36] V. Cherepanov,[36] Y. Erdogan,[36] G. Flügge,[36] H. Geenen,[36] M. Geisler,[36] W. Haj Ahmad,[36] F. Hoehle,[36] B. Kargoll,[36] T. Kress,[36] Y. Kuessel,[36] A. Nowack,[36] L. Perchalla,[36] O. Pooth,[36] P. Sauerland,[36] A. Stahl,[36] M. Aldaya Martin,[37] J. Behr,[37] W. Behrenhoff,[37] U. Behrens,[37] M. Bergholz,[37,r] A. Bethani,[37] K. Borras,[37] A. Burgmeier,[37] A. Cakir,[37] L. Calligaris,[37] A. Campbell,[37] E. Castro,[37] F. Costanza,[37] D. Dammann,[37] C. Diez Pardos,[37] G. Eckerlin,[37] D. Eckstein,[37] G. Flucke,[37] A. Geiser,[37] I. Glushkov,[37] P. Gunnellini,[37] S. Habib,[37] J. Hauk,[37] G. Hellwig,[37] H. Jung,[37] M. Kasemann,[37] P. Katsas,[37] C. Kleinwort,[37] H. Kluge,[37] A. Knutsson,[37] M. Krämer,[37] D. Krücker,[37] E. Kuznetsova,[37] W. Lange,[37] W. Lohmann,[37,r] B. Lutz,[37] R. Mankel,[37] I. Marfin,[37] M. Marienfeld,[37] I.-A. Melzer-Pellmann,[37] A. B. Meyer,[37] J. Mnich,[37] A. Mussgiller,[37] S. Naumann-Emme,[37] J. Olzem,[37] H. Perrey,[37] A. Petrukhin,[37] D. Pitzl,[37] A. Raspereza,[37] P. M. Ribeiro Cipriano,[37] C. Riedl,[37] E. Ron,[37] M. Rosin,[37] J. Salfeld-Nebgen,[37] R. Schmidt,[37,r] T. Schoerner-Sadenius,[37] N. Sen,[37] A. Spiridonov,[37] M. Stein,[37] R. Walsh,[37] C. Wissing,[37] C. Autermann,[38] V. Blobel,[38] J. Draeger,[38] H. Enderle,[38] J. Erfle,[38] U. Gebbert,[38] M. Görner,[38] T. Hermanns,[38] R. S. Höing,[38] K. Kaschube,[38] G. Kaussen,[38] H. Kirschenmann,[38] R. Klanner,[38] J. Lange,[38] B. Mura,[38] F. Nowak,[38] T. Peiffer,[38] N. Pietsch,[38] D. Rathjens,[38] C. Sander,[38] H. Schettler,[38] P. Schleper,[38] E. Schlieckau,[38] A. Schmidt,[38] M. Schröder,[38] T. Schum,[38] M. Seidel,[38] V. Sola,[38] H. Stadie,[38] G. Steinbrück,[38] J. Thomsen,[38] L. Vanelderen,[38] C. Barth,[39] J. Berger,[39] C. Böser,[39] T. Chwalek,[39] W. De Boer,[39] A. Descroix,[39] A. Dierlamm,[39] M. Feindt,[39] M. Guthoff,[39,f] C. Hackstein,[39] F. Hartmann,[39] T. Hauth,[39,f] M. Heinrich,[39] H. Held,[39] K. H. Hoffmann,[39] S. Honc,[39] I. Katkov,[39,q] J. R. Komaragiri,[39] P. Lobelle Pardo,[39] D. Martschei,[39] S. Mueller,[39] Th. Müller,[39] M. Niegel,[39] A. Nürnberg,[39] O. Oberst,[39] A. Oehler,[39] J. Ott,[39] G. Quast,[39] K. Rabbertz,[39] F. Ratnikov,[39] N. Ratnikova,[39] S. Röcker,[39] A. Scheurer,[39] F.-P. Schilling,[39] G. Schott,[39] H. J. Simonis,[39] F. M. Stober,[39] D. Troendle,[39] R. Ulrich,[39] J. Wagner-Kuhr,[39] S. Wayand,[39] T. Weiler,[39] M. Zeise,[39] G. Daskalakis,[40] T. Geralis,[40] S. Kesisoglou,[40] A. Kyriakis,[40] D. Loukas,[40] I. Manolakos,[40] A. Markou,[40] C. Markou,[40] C. Mavrommatis,[40] E. Ntomari,[40] L. Gouskos,[41] T. J. Mertzimekis,[41] A. Panagiotou,[41] N. Saoulidou,[41] I. Evangelou,[42] C. Foudas,[42] P. Kokkas,[42] N. Manthos,[42] I. Papadopoulos,[42] V. Patras,[42] G. Bencze,[43] C. Hajdu,[43] P. Hidas,[43] D. Horvath,[43,s] F. Sikler,[43] V. Veszpremi,[43] G. Vesztergombi,[43,t] N. Beni,[44] S. Czellar,[44] J. Molnar,[44] J. Palinkas,[44] Z. Szillasi,[44] J. Karancsi,[45] P. Raics,[45] Z. L. Trocsanyi,[45] B. Ujvari,[45] S. B. Beri,[46] V. Bhatnagar,[46] N. Dhingra,[46] R. Gupta,[46] M. Kaur,[46] M. Z. Mehta,[46] N. Nishu,[46] L. K. Saini,[46] A. Sharma,[46] J. Singh,[46] Ashok Kumar,[47] Arun Kumar,[47] S. Ahuja,[47] A. Bhardwaj,[47] B. C. Choudhary,[47] S. Malhotra,[47] M. Naimuddin,[47] K. Ranjan,[47] V. Sharma,[47] R. K. Shivpuri,[47] S. Banerjee,[48] S. Bhattacharya,[48] S. Dutta,[48] B. Gomber,[48] Sa. Jain,[48] Sh. Jain,[48] R. Khurana,[48] S. Sarkar,[48] M. Sharan,[48] A. Abdulsalam,[49] R. K. Choudhury,[49] D. Dutta,[49] S. Kailas,[49] V. Kumar,[49] P. Mehta,[49] A. K. Mohanty,[49,f] L. M. Pant,[49] P. Shukla,[49] T. Aziz,[50] S. Ganguly,[50] M. Guchait,[50,u] M. Maity,[50,v] G. Majumder,[50] K. Mazumdar,[50] G. B. Mohanty,[50] B. Parida,[50] K. Sudhakar,[50] N. Wickramage,[50] S. Banerjee,[51] S. Dugad,[51] H. Arfaei,[52] H. Bakhshiansohi,[52,w] S. M. Etesami,[52,x] A. Fahim,[52,w] M. Hashemi,[52] H. Hesari,[52] A. Jafari,[52,w] M. Khakzad,[52] M. Mohammadi Najafabadi,[52] S. Paktinat Mehdiabadi,[52] B. Safarzadeh,[52,y] M. Zeinali,[52,x] M. Abbrescia,[53a,53b] L. Barbone,[53a,53b] C. Calabria,[53a,53b,f] S. S. Chhibra,[53a,53b] A. Colaleo,[53a] D. Creanza,[53a,53c] N. De Filippis,[53a,53c,f] M. De Palma,[53a,53b] L. Fiore,[53a] G. Iaselli,[53a,53c] L. Lusito,[53a,53b] G. 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